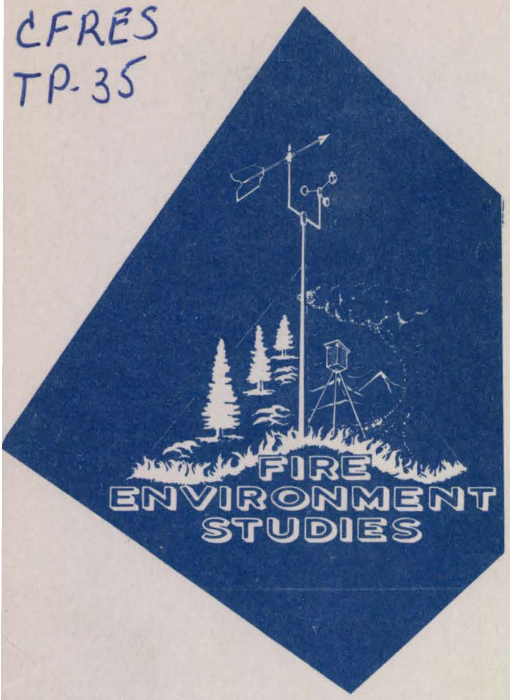

FOREST SERVICE - U.S. DEPARTMENT OF AGRICULTURE

PRESCRIBED BURN FIRECLIMATE SURVEY 4-57

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PACIFIC SOUTHWEST FOREST & RANGE EXPERIMENT STATION
KEITH ARNOLD, DIRECTOR . . . . BERKELEY CALIFORNIA

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Pacific Southwest Forest and Range Experiment Station

and

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U. S. Weather Bureau

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U. S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE
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FOREWORD

Fireclimate Studies--Their Purpose

Experience and research have taught fire fighters a good deal about wildland fire. Its general relationship to weather, fuels, and topography is well known. Application of this knowledge to control of fire is frequently hampered by lack of information about the behavior of fireclimate in specific places--how wind, temperature, humidity, and fuel moisture are affected by topography, water bodies, season, and the fire itself. The existing system of weather stations provides enough information for general weather forecasts but not enough to define local fireclimate patterns. The stations are relatively few, widely spaced, and seldom equipped with recording instruments. They gather only momentary samples of weather conditions and provide no information on the way the fire itself affects the patterns.

To obtain this needed information, the Station has started studies aimed at establishing some of the principles controlling local fireclimate patterns and the effect of fire on these patterns. A four-pronged attack will be made on the problem:

1. Semi-permanent fireclimate surveys wherein distinct topographic types will be intensively instrumented for one or more years primarily for the study of variations in local fireclimate patterns in relation to more general weather patterns.

2. Temporary or mobile surveys that will permit exploratory studies of fireclimate patterns around prescribed burns and wildfires and short-term detailed studies of various phases of broader scale fireclimate patterns.

3. Analysis of existing fire and weather records to establish, if possible, the relation of pattern of past fires to weather patterns.

4. Controlled laboratory studies aimed at determination of the fundamental laws governing fireclimate patterns and effects of fire on these patterns.

ABSTRACT

Prescribed burn fireclimate survey 4-57 was the last of four prescribed burns studied in 1957. The survey was conducted in a portion of a well defined canyon opening into a relatively broad valley--topographic features supposedly ideal for the normal mountain wind pattern of anabatic (up slope, up canyon) and katabatic (down slope, down canyon) winds.

Averaged over time periods of one hour or more the classic pattern of mountain and valley winds did appear in a generalized way. Over short periods quite different patterns were apparent. Fire behavior appeared to be more closely associated with these short periods patterns than with the generalized pattern for the area.

The survey emphasized the need for considering all factors of fire environment in their relation to each other in predicting fire behavior.

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THE SURVEY AREA

This fireclimate survey was made on the Gunn Ranch property, about 70 miles west of Sacramento, California. The prescribed burn area extended for nearly two miles along the southwest side of Brushy Canyon on the western slope of the Vaca Mountains. Along the burn area the canyon ran in a generally southeast-northwest direction (fig. 1). A short distance beyond the southernmost end of the burn the canyon curved sharply to the west and continued in this direction for about two miles to where it joined Putah Creek in broad Berryessa Valley1/.

The topography of the burn area was characterized by a number of small but well defined ravines leading into Brushy Canyon (fig. 2). The ravines were separated by spur ridges sloping steeply down from the main ridge dividing Brushy Canyon from Berryessa Valley. The east side of Brushy Canyon rose to the main divide of the Vaca Mountains.

Most of the burn area was covered with a heavy stand of chaparral made up chiefly of chamise, ceanothus species, manzanita, and scattered digger pine. Groves of oak occurred in the wider parts of the canyon bottom. A narrow band of grass-woodland fuel type predominated on the top of the main divide between Brushy Canyon and Berryessa Valley (fig. 3). Except in areas where burning had been attempted in previous years there was a small proportion of dead material to green material in the chaparral fuel and very little ground litter.

1/ Now Lake Berryessa.

Figure 1.--Prescribed burn fireclimate survey 4-57.

Figure 2.--Down canyon (south) view of Brushy Canyon.

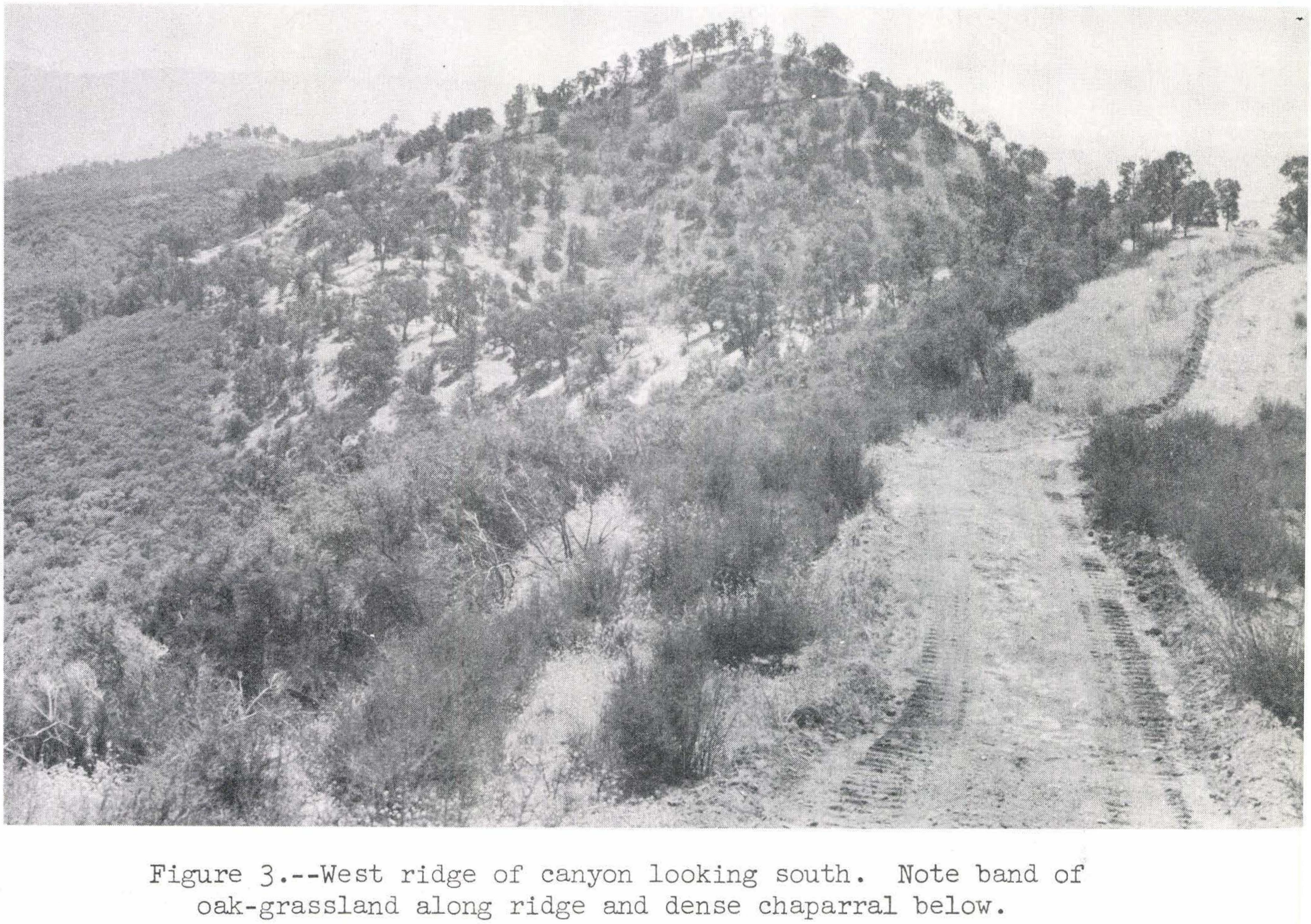

Figure 3.--West ridge of canyon looking south. Note band of oak-grassland along ridge and dense chaparral below.

Figure 4.--Station 3.

Figure 5.--Station 7

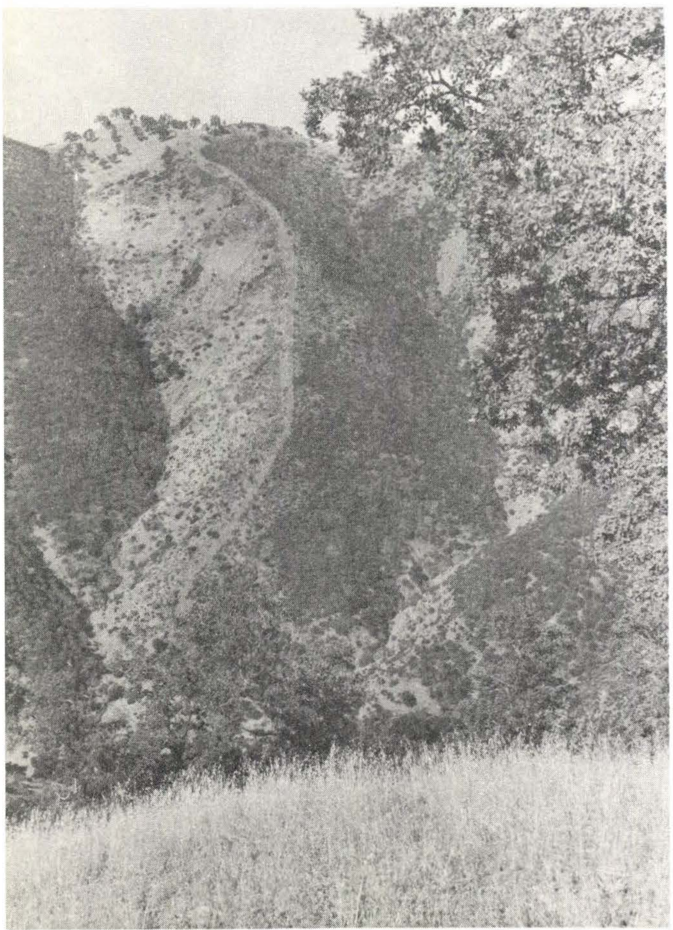

Figure 6.--Transect T-1 at northwest end of burn.

SURVEY PROCEDURE

Six sites were selected for our available wind recording equipment. The steep topography made it necessary that we install the stations on the edge of the burn in the canyon bottom and on ridge tops. Station 1 was located in the canyon bottom a few hundred feet downstream from where the canyon split into two major forks (fig. 1). The station was somewhat sheltered by trees in the upstream direction but there was no vegetation influence on other winds. The canyon bottom was about 200 feet wide in this area. A hygrothermograph was included in the equipment at Station 1.

Station 2 was in the west fork of the canyon, approximately 100 feet up the east slope and 40 to 50 feet higher than the canyon bottom. In this position the station was not influenced by vegetation in the canyon bottom.

Station 3 was near the end of the ridge separating the canyon forks and well exposed to winds from all directions (fig. 4). Station 3 was about 600 feet higher than Station 2, 300-400 feet lower than the main ridge to the west and about 1,000 feet lower than the divide to the east.

Recording stations 4, 6 and 7 were on the main ridge dividing Brushy Canyon from Berryessa Valley. Station 4 was on a small knoll near the southwest corner of the burn. The station was well exposed to winds from all directions. A hygrothermograph was also installed at this station.

Station 6 was in the bottom of one of the major saddles along the ridge. It was somewhat sheltered by the topography to the northwest and southeast but otherwise well exposed.

Station 7 was set up on the highest point of the ridge within the burn boundaries (fig. 5). Exposure of this station to all winds was very good.

In addition to the recording stations some measurements were made manually at two other stations in major saddles along the main ridge (Stations 5 and 8, fig. 1). Standard Robinson 3 cup anemometers were used at these stations. Manual measurements of wind speed and direction, temperature and humidity were made at 9 points along the spur ridge sloping into the canyon at the northwest end of the fire (T-1, figs. 1 and 6). Wind speed measurements along this transect were made with a Dwyer wind meter. Direction was determined with a light ribbon and temperature and humidity measurements with a sling psychrometer. Similar measurements were also made in the upper part of the ravine below Station 6 (T-2, fig. 1) and along the 1,750 foot contour below Station 7 (T-3, fig. 1).

Observations were started on September 4 and continued until September 20.

GENERAL WEATHER

The weather during the period of the survey ranged from hot to cool. During the first few days the temperature trend was upward. In the survey area, and in the coastal region of central California in general, highest temperatures were observed on September 7, when readings of over 100° F. prevailed. Maximum temperatures from September 9 to 13 were near or slightly below normal. Further cooling occurred in the area on September 14. Temperatures then remained well below seasonal normal until September 19 when a warming trend began.

The most prominent feature of the weather pattern aloft in the general area was the presence of a cold low near the California coast during much of the survey period. This cold low wandered around to the south and southwest of the survey area (fig. 7) and was responsible for mostly easterly and southerly flow aloft. Almost no west winds were observed above the 700 millibar level at Oakland during the period. The low aloft moved inland the night of September 16, apparently passing just south of the survey area. Upper winds shifted to northerly and temperature dropped at all levels with the passage of the low aloft. Only during the last few days of the survey when the flow aloft was northerly was there any evidence of the pattern aloft affecting the wind pattern in the survey area.

On the surface weather maps the thermal low pressure trough extending from the desert regions up through California was evident during most of the survey period. On September 13 the trough began to broaden and gradually shifted eastward as the cold low aloft approached the central California coast. By early on September 16 the trough had moved eastward to Idaho, Utah and Arizona and on the 17th and 18th it was completely obliterated as the cold low aloft moved from California into the Great Basin area. The instability associated with the cold low was sufficient to cause showers and thunderstorms particularly in the San Joaquin Valley and the southern Sierras.

The depth of the layer of marine air, as indicated by the base of the inversion on the Oakland radiosonde observations, varied considerably during the period (fig. 8). On September 6 and 7, during the hottest weather, the base of the inversion was at the surface. After rising to about 2,500 feet on the 10th and 11th, and lowering somewhat on the 12th and 13th, it began to rise steadily on the 14th as cool marine air spread into the central California coastal area. The marine layer continued to deepen reaching a maximum of about 8,000 feet with the passage of the cold low aloft the night of September 16.

No definite fronts moved through the survey area during the period. A cold front entered northwestern California on September 7 and spread across the extreme northern portion of the state. Although the front itself did not move farther south it may have been a factor in deepening the marine layer and ending the hot spell on September 8 and 9.

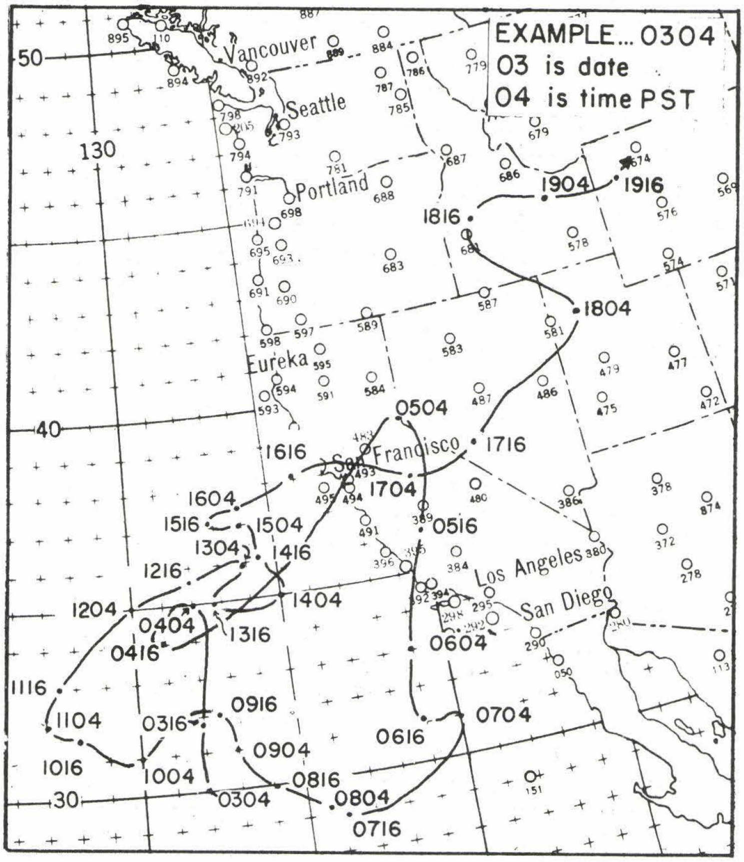

Figure 7.--Path of 500 MB Low, Sept. 3-19, 1957.

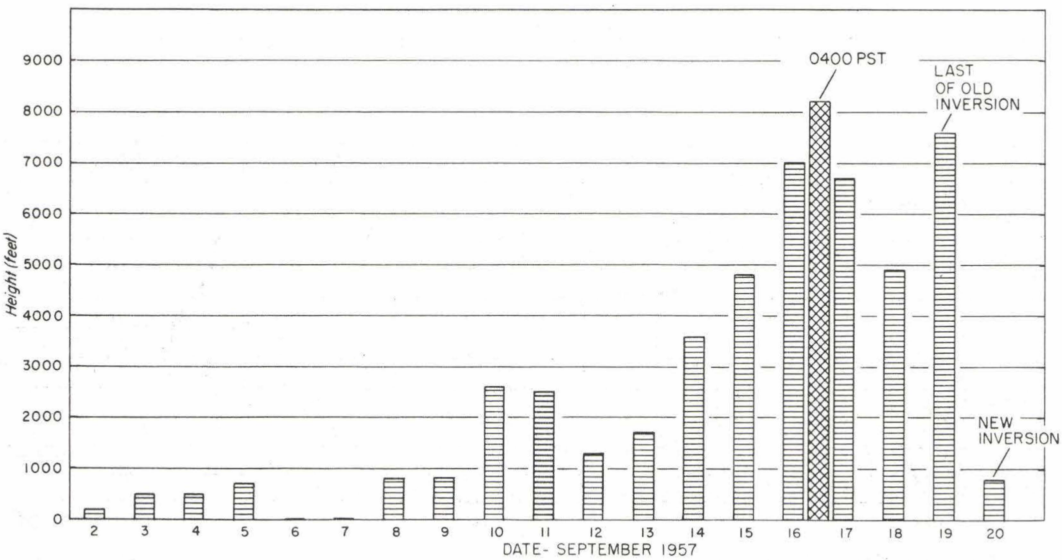

Figure 8.--Height of inversion base at Oakland, 1,600 P.

LOCAL WIND PATTERNS

Our observations showed that we could usually expect a southwest or west wind (roughly at right angles to the canyon) during the day at the higher ridges and a northwest or north wind at night. Observations within the canyon, if averaged over periods of an hour or more, indicated the classical wind pattern for mountain canyons--up canyon, up slope winds during the day and down canyon, down slope winds at night. In the canyon bottom at Station 1 the change in wind from a light down-canyon wind to a stronger up canyon flow occurred regularly a short time after sunrise. Frequently this shift was very abrupt (fig. 9). The evening wind shift occurred much less abruptly, sometimes requiring up to two hours to complete the shift from up canyon to down canyon wind (fig. 10). The time of evening shift was also less consistent than the morning change--sometimes starting as early as 1700 and other days not until 1830 or 1900. This same pattern of wind flow persisted throughout the survey period (fig. 11) except on September 19 and 20. On these two days a northerly flow of winds aloft

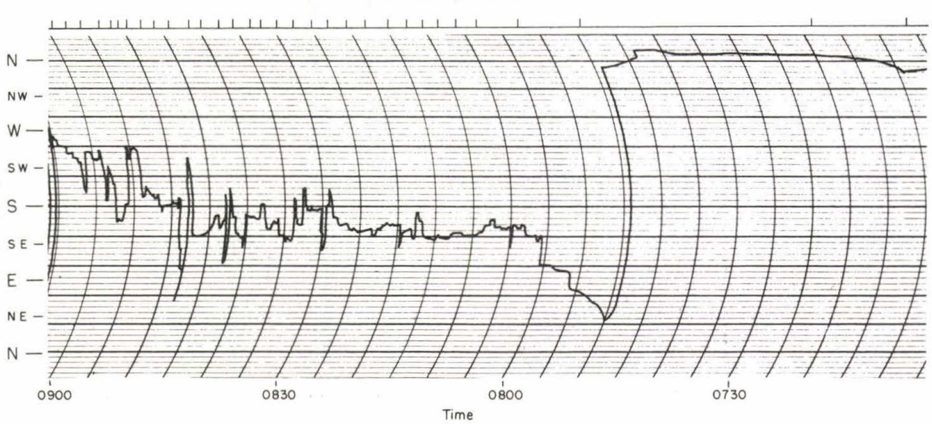

Figure 9.--Morning wind shift, Station 1, Sept. 16, 1957.

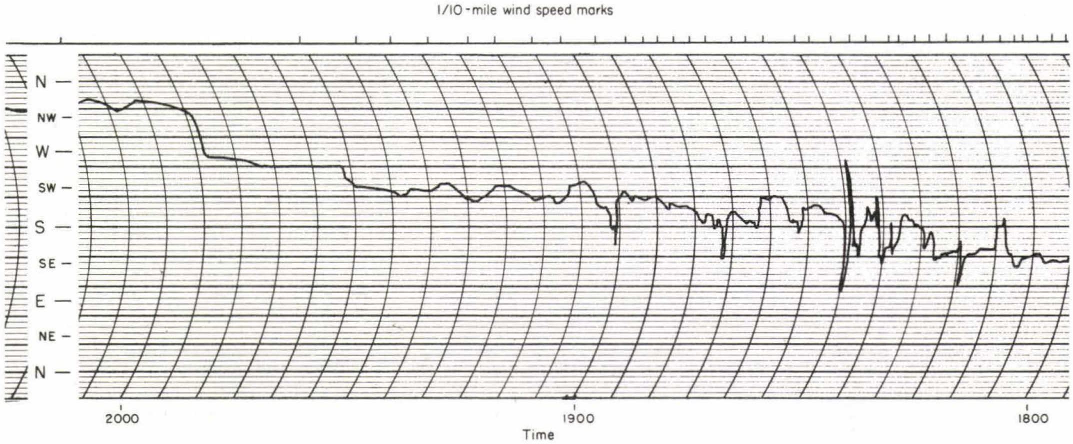

Figure 10.--Evening wind shift, Station 1, September 16, 1957.

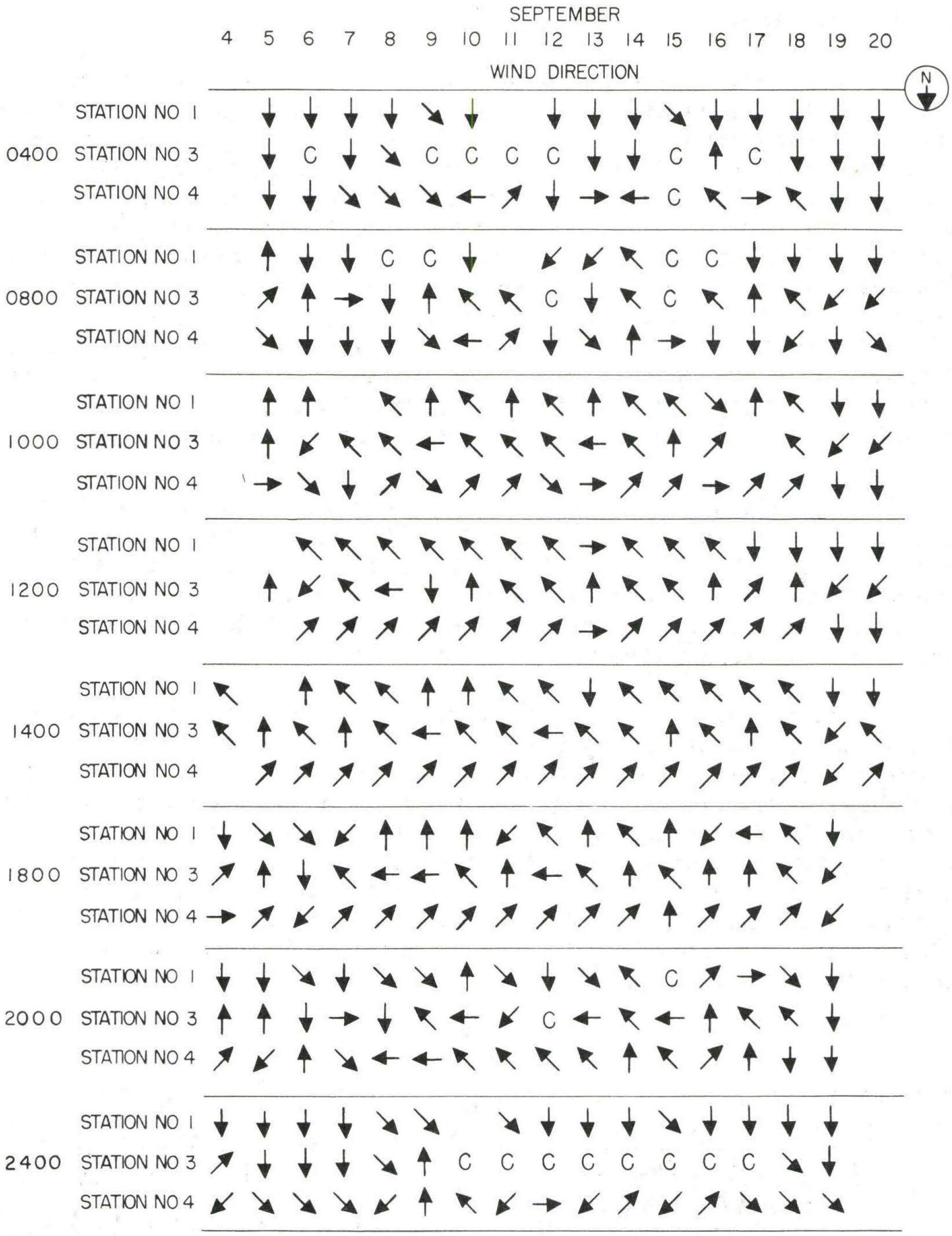

Figure 11.--Hourly average wind direction for selected hours, September 4-20, 1957.

resulted in north or northeast winds both day and night within our survey area.

More detailed scrutiny of the continuous records, supplemented by the manually made observations at other points within the canyon, showed that the described flow was only a general pattern and, for short periods at least, there were major variations from this pattern. Frequently the air flow during the day was down the slopes on the west side of the canyon, sometimes reaching the canyon bottom, at other times coming only part way down the slope. The down slope wind often seemed more pronounced in the several ravines leading into the main canyon. At times it appeared as if there was a down canyon wind in the ravines, a wind up the main canyon and on the spur ridges and a cross canyon wind at the higher levels. The wind movement in the first 150 to 200 feet change in elevation below the ridge top was particularly variable.

The tendency for the wind to blow down the slope is illustrated by the wind direction trace at Station 1 from 1150 to 1400 hours on September 12 (fig. 12). Although the trace shows that the wind during this period was predominately from the south and southeast (up canyon) there were many short periods when the wind was from a westerly direction or down slope.

The manual measurements taken along the spur ridge marking the northern end of the burn area (T-1, fig. 1) also show the extreme variability in winds along the slope. The transect shown in figure 13 was made during the afternoon of September 5, On the lower two-thirds of the slope wind direction was generally up canyon or quartering up slope. The prevailing west wind was predominant at Station A, typical of other ridge points at the higher elevations. The tendency for the wind to blow in a nearly opposite direction at Stations B and C would indicate the presence of a horizontal or roll eddy in this area.

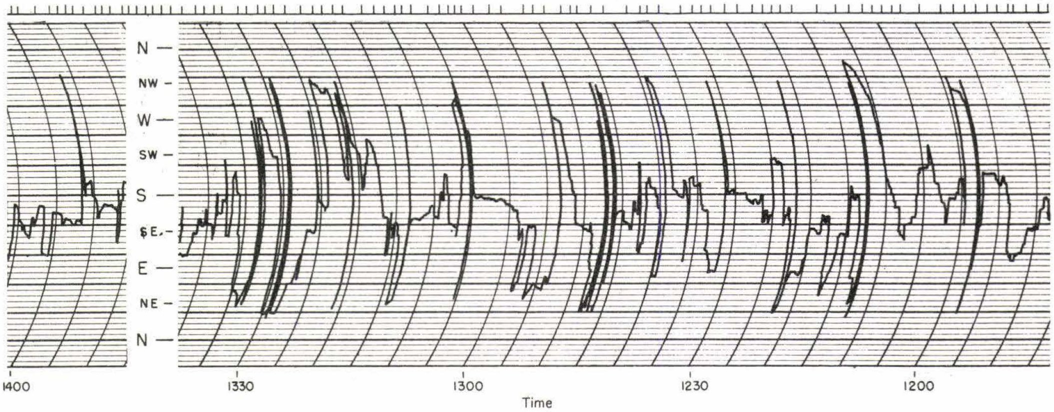

Figure 12.--Wind direction trace, Station 1, 1150 hours to 1400 hours, September 12, 1957.

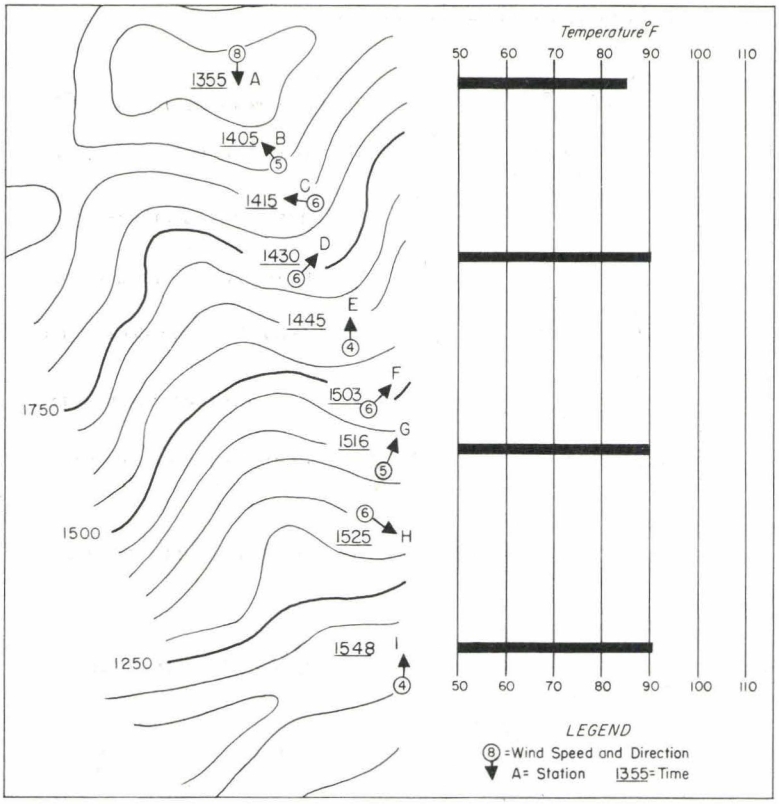

Figure 13.--Wind and temperature transect at T-1, September 5, 1957.

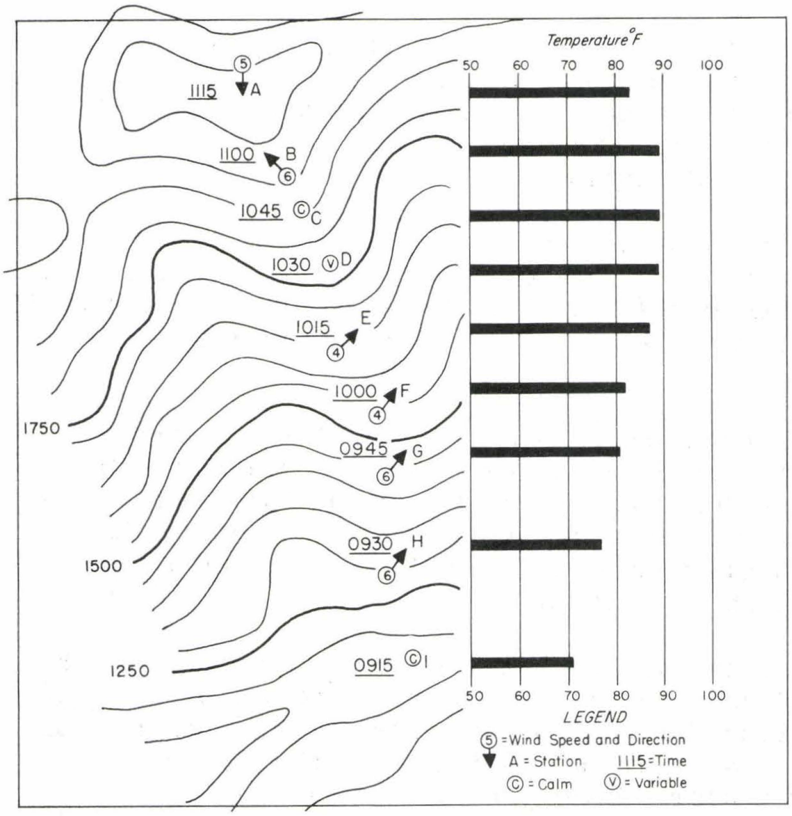

Figure 14.--Wind and temperature transect at T-1, September 6, 1957.

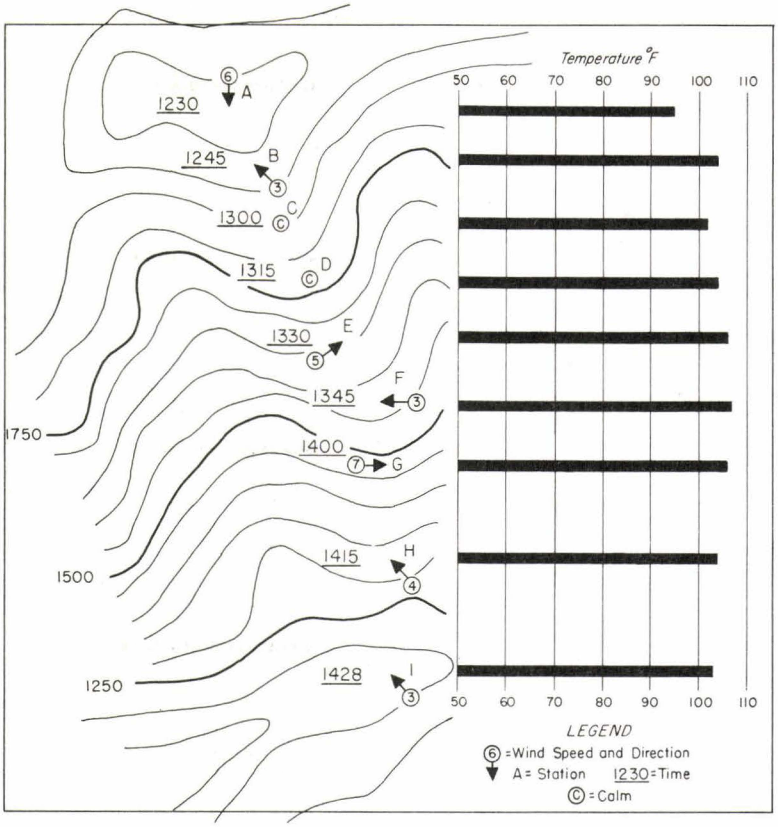

Figure 15.--Wind and temperature transect at T-1, September 7, 1957.

A similar pattern of air movement was also present during the morning hours. A transect taken on the morning of September 6 (fig. 14) showed a quartering up slope wind on the lower half of the spur ridge, a roll eddy in the vicinity of Station B and light, variable winds at Stations C and D.

When heating was very strong such as on September 7 when temperatures reached 107° in the canyon the winds along the transect became extremely variable (fig. 15). The roll eddy in the vicinity of Station B still persisted but the wind at other points was both gusty and variable.

Most common afternoon wind pattern for the burn area is shown in figure 16. On the ridge tops and over the canyon the prevailing wind was from the southwest. In the lower part of the canyon an up canyon flow was predominant. On the upper half of the slopes and extending down in the ravines was an area where the winds were variable and gusty.

Of interest, too, is the temperature pattern found in the canyon. The continuous records at Station 1 (canyon bottom) and Station 4 (ridge top) showed a pattern characteristic of mountain canyons (fig. 17). At night and during the early daylight hours there was usually a strong inversion, sometimes of 20 degrees or more. During the warmer part of the day the canyon bottom station

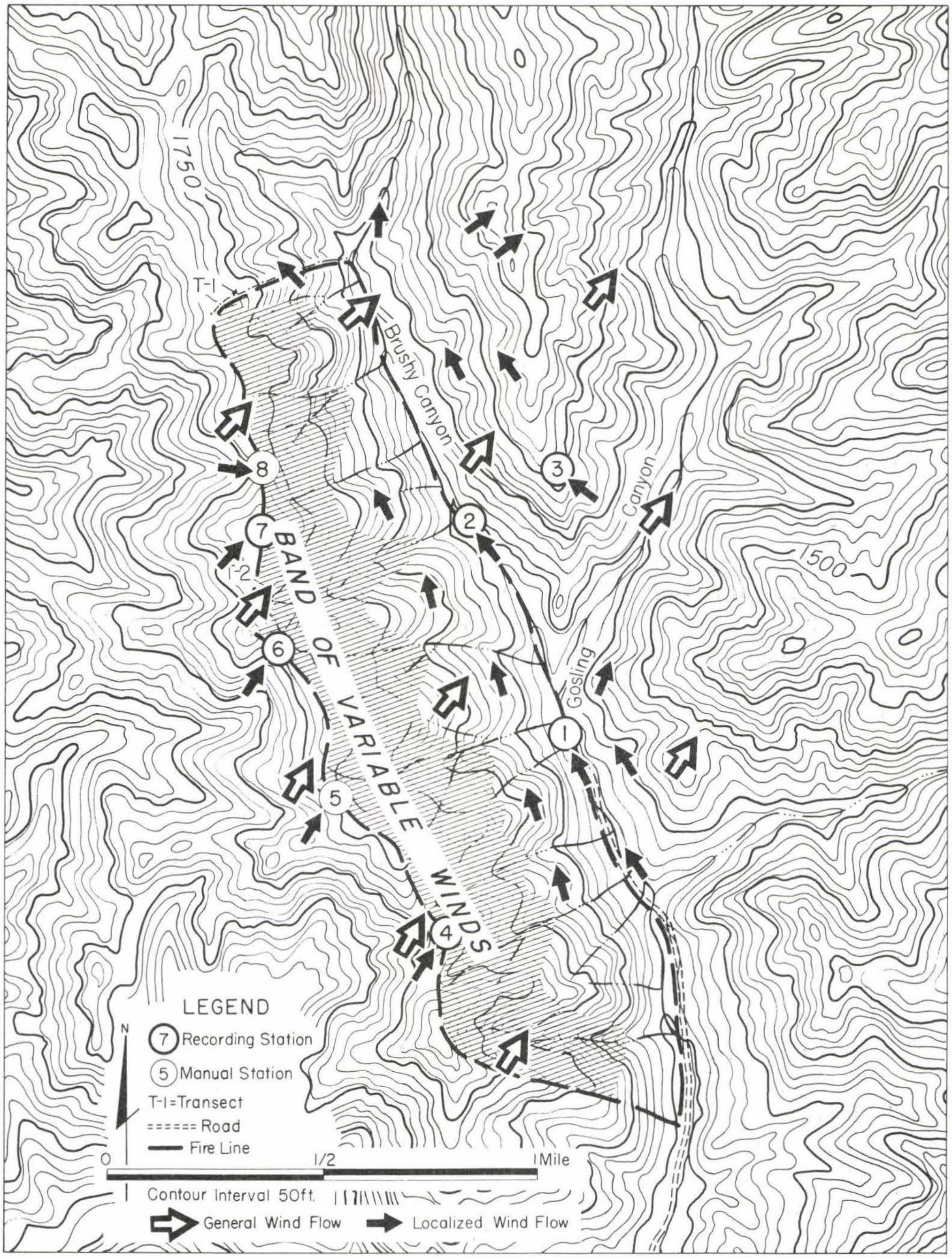

Figure 16.--Predominant afternoon air flow pattern for prescribed burn survey area 4-57.

frequently indicated temperatures 4-6 degrees higher than the ridge top--approximately the adiabatic difference expected for the change in elevation (800 feet). Manual temperature measurements showed, however, that most of this temperature difference probably occurred in the first 50 to 150 feet down from the ridge top (fig. 15). On all of the traverses made along T-1 the daytime temperature at the ridge top was less than at Station B.

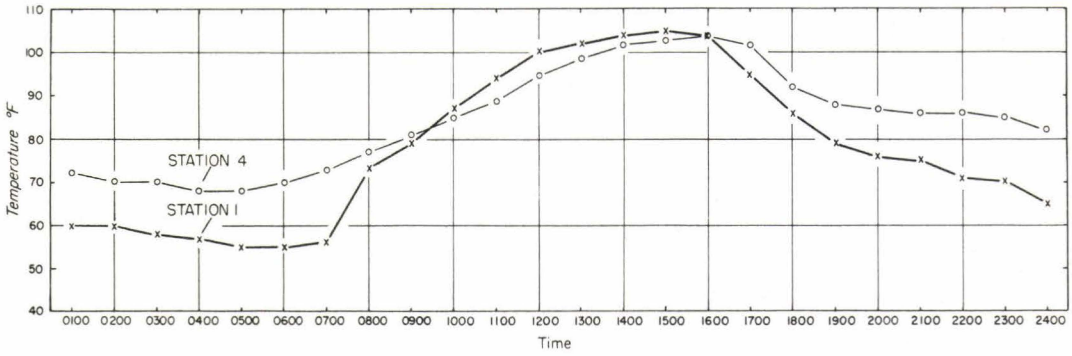

Figure 17.--Temperature regime at canyon bottom and ridge top station, September 6, 1959.

The temperature pattern within the canyon may help explain the observed wind pattern. The air arriving at the ridge top from the west was cooler and hence more dense than the air in the canyon. This relatively cool air would tend to flow under the warm air until it in turn was warmed by adiabatic heating and by contact with the ground to the canyon air temperature. Air within the ravines could be expected to be warmer than the air in the main canyon hence the down slope flow would be more pronounced in the ravines and would penetrate further down the slope.

FIRE BEHAVIOR

Two attempts were made to burn the area--the first on September 12 during "normal" weather for the area and the second during the dry north wind condition on September 20. Neither attempt was successful in burning more than a small fraction of the area.

On September 12 the west fire line and the ravine below the north line were fired. Some firing was also done outside the proposed burn in a steep grassy area on the east side of Brushy Canyon. This attempt to burn succeeded only in the grass areas along the fire line and in the area on the east side of the canyon. Very little of the brush fuel burned. Maximum temperature for the day was 86° and the minimum relative humidity 22 percent. Average temperature for the afternoon, however, was about 82° and relative humidity 28 percent. Wind at Station 7 was from the southwest and averaged one mile per hour.

Although the burn did not accomplish its purpose of removing the brush, the smoke from scattered small fires in the area did verify the air flow pattern our observations had indicated was probable.

The movement of air cross canyon and up canyon at the same time is shown in figure 18. This picture was taken from the east side of Brushy Canyon looking toward the smoke at the southern edge

of the burn. At the upper levels the smoke is moving at an angle across the canyon with the prevailing southwest wind. In the canyon bottom the smoke is moving up canyon with the valley wind.

Figure 19 illustrates a combination of down slope and cross canyon winds. This picture was taken looking southwest across the canyon toward smoke on the spur ridge running down into the canyon from Station 7. Here the smoke is again moving at an angle across the canyon with the prevailing wind but is also moving downslope in both ravines.

Figure 18.--Up canyon and cross canyon winds. Smoke is at southern edge of burn.

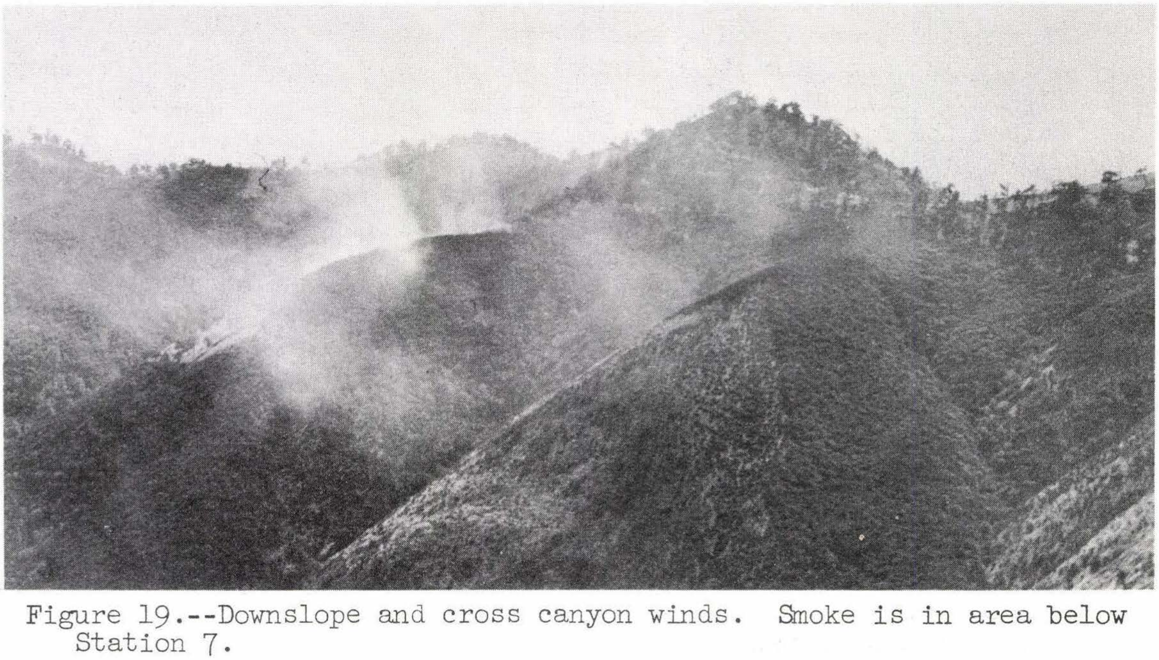

Figure 19.--Downslope and cross canyon winds. Smoke is in area below Station 7.

Figure 20.--Down slope winds in ravines at the northern end of the burn area.

Figure 21.--Down slope and up slope winds in ravines at the northern end of the burn area.

Another illustration of down slope winds is pictured in figure 20 which shows smoke movement at the north end of the burn. The north fire line where transects of the temperature and wind were made is in the right of the picture. At the time the picture was taken the smoke was moving down slope in both of the ravines in view. A few minutes later the pattern changed (fig. 21). Now the smoke in the ravine to the south is moving up slope but in the ravine to the right the down slope movement is still present.

The picture shown in figure 22 was taken looking into the bottom of the main canyon in the same area as shown in figures 20 and 21 during the time the area outside the proposed burn was being fired. The smoke indicates a strong up canyon flow in the canyon bottom.

The attempt to burn the area on September 20 was somewhat more successful than the September 12 effort. Firing was started about 1000 hours with a 5-8 mile-per-hour north wind, a temperature of 82 and relative humidity of 18 percent. Maximum temperature for the day was 87 and minimum humidity 14 percent.

Firing was started in Brushy Canyon near the northeast corner of the burn area and carried along the toe of the slope in the canyon bottom. The fire burned well in the heavier fuels near the bottom of the canyon and a few hot "runs" started up the canyon slopes. None of these runs, however, went more than halfway up the slope and no sustained fire front developed.

The failure of the fire to burn better under the favorable moisture conditions and steep topography can be explained by the arrangement of the fuel and by the wind direction. The mature chaparral in this area had very little surface fuel and a rather high green fuel to dead fuel ratio. With these fuel conditions fires do not burn well unless much of the convective heat produced is available for pre-heating the fuels ahead of the fire, such as would be the case with strong winds or steep slopes.

In the attempt to burn the area on September 20 the fire burned well on the lower slopes of the canyon as could be expected with the steep topography. The wind, however, was down canyon or at right angles to the slope. Once the fire burned up the slope to where wind speeds were stronger the wind dissipated much of the convective heat. As a result the fire did not spread uphill beyond the point where the cross-slope wind counteracted the slope effect (fig. 23).

The failure of the burn on September 12 was also likely due to the wind pattern. In this case the effect of slope on the fire was offset by the erratic winds that were blowing both down slope and cross slope. With the higher humidity and fuel moisture less adverse wind was required to nullify the slope effect than was needed on September 20.

Figure 22.--Up canyon wind in bottom of canyon at north end of burn area.

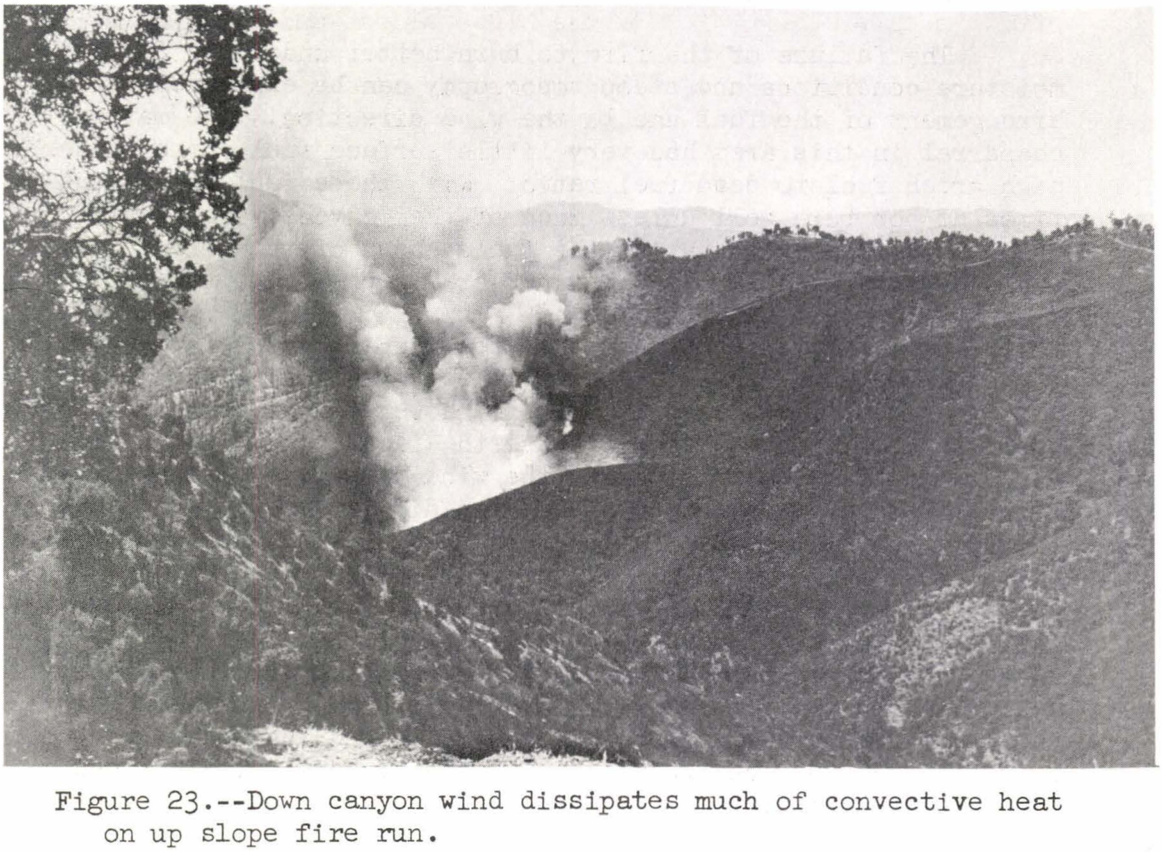

Figure 23.--Down canyon wind dissipates much of convective heat on up slope fire run.

CONCLUSIONS

Observations in this survey showed that the wind pattern in a mountain canyon when established for short time intervals may be considerably different than when the observations are averaged over a longer period--say an hour or more. Because fire responds quickly to changes in wind, fire behavior may be expected to be more closely associated with the short period patterns than with the longer term average.

Instrumentation for the survey was sufficient only to give a small sample of surface conditions. This sample, coupled with observations of smoke movement, showed that the air flow patterns in these small, sharply defined canyons can be extremely complex. The patterns may be greatly affected not only by the synoptic weather but also by the effects of very localized differential heating. The observations strongly suggested that air movement in the canyon might occur in layers--each layer moving in a different direction.

The survey and the behavior of the fire emphasized again the need for considering all factors of fire environment in their relation to each other in trying to predict the probable behavior of a wildland fire. For example on September 20 when the second attempt to burn the survey area was made, many of the ingredients for a hot, fast running fire were present--low humidity, dry fuel, moderate wind, and steep slopes. The wind direction, however, offset much of the effect of the steep slopes and the fuel arrangement nullified the low humidity and low fuel moisture. As a result the fire did not burn well and failed to accomplish its purpose. With wind and slope effects in the same direction and a slightly more compact fuel it is probable that the fire would have burned very hot and been difficult to control. It is the integrated effect of all the environmental factors that control fire behavior and not necessarily the level of any one or two factors.

This survey also pointed up the need for more complete measurements of environmental factors in field research in fire-climate patterns and fire behavior. A few surface measurements are not enough--we need to know what is happening in the vertical direction as well as the horizontal.